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Expert players accurately detect an opponent's movement intentions through sound alone.

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## Abstract

Sounds offer a rich source of information about events taking place in our physical and social environment. However, outside the domains of speech and music, little is known about whether humans can recognize and act upon the intentions of another agent's actions detected through auditory information alone. In this study we assessed whether intention can be inferred from the sound an action makes, and in turn, whether this information can be used to prospectively guide movement. In two experiments experienced and novice basketball players had to virtually intercept an attacker by listening to audio recordings of that player's movements. In the first experiment participants had to move a slider, while in the second one their body, to block the perceived passage of the attacker as they would in a real basketball game. Combinations of deceptive and non-deceptive movements were used to see if novice and/or experienced listeners could perceive the attacker's intentions through sound alone. We showed that basketball players were able to more accurately predict final running direction compared to non-players, particularly in the second experiment when the interceptive action was more basketball specific. We suggest that athletes present better action anticipation by being able to pick up and use the relevant kinematic features of deceptive movement from event-related sounds alone. This result suggests that action intention can be perceived through the sound a movement makes and that the ability to determine another person's action intention from the information conveyed through sound is honed through practice.

*Keywords:* Action anticipation, Event related sound perception, Information Movement guidance, Expert/novice differences

Although our acoustic environment is structured by the physical and social events in the world around us (Gaver, 1993; Rosenblum, 2004; Steenson & Rodger, 2015), research on how we perceive and respond to arguably the most salient types of events, namely the actions of others, has tended to focus primarily on the visual modality (McAleer & Pollick, 2008). Indeed, outside of the domains of music and speech, very little is known about whether people can pick up and act upon information about the intentional behaviour of others through the auditory modality alone. The ‘supramodal theory of the brain’ (Rosenblum, Dias, & Dorsi, 2016), which has its basis in ecological psychology and enactive cognitive science (Gibson, 2014; Noë, 2004), argues that as long as information relevant to a given task is available to a perceiver, their brain is not constrained by the sensory modality through which the event based information is picked up. In other words, if a person’s actions structure the patterning of information in both the optic and acoustic arrays, as would be the case when walking on a gravel surface, this information may be accurately detected through either modality. Importantly, if one sensory modality is unavailable (e.g. vision is occluded), then the brain may make use of the same information in another modality (e.g. audition) (Rosenblum et al., 2016). Furthermore, these behavioural results are supported by neuronal studies that show, in non-human primates and humans, that action based sounds are encoded in the same mirror circuits that are activated during the visual recognition of actions and also action execution (Kohler, Keysers, Umiltà, Fogassi, Gallese, and Rizzolatti, 2002; Gazzola, Aziz-Zadeh, Keysers, 2006). Hence, if patterns of movement can specify the intention of an agent visually, and relevant correlated information about these patterns of movement is also contained in sound, then it may be possible for perceivers to pick up and act solely upon the available information. In this paper, we tested the hypothesis that participants will be able to pick up and use the information that specifies the future course of action of an attacking player in basketball using sound alone.

Our ability to perceive the action intention of others and use this information to regulate our own movements is crucial to successfully performing many everyday activities such as driving a car, or crossing a road. Previous research has shown that experience of relevant actions, and the action

capabilities of the actor, can influence our perception of the world around us (Witt & Riley, 2014). Furthermore, other research has also shown that increased levels of practice or experience heighten our ability to tune into relevant sensory information that specifies a future course of action (Brault, Bideau, Kulpa, & Craig, 2012; Correia, Araújo, Cummins, & Craig, 2012) and enhance the level of action representation in the brain (Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005; Calvo-Merino, Grezes, Glaser, Passingham, & Haggard, 2006). Through these mechanisms it is hypothesised that expert sports players are better able to predict whether a basketball shot will result in a basket (Aglioti, Cesari, Romani, & Urgesi, 2008), detect when an attacker is trying to use his/her movements to deceive an opponent in rugby (Brault et al., 2012) and to anticipate deceptive action in soccer (Tomeo, Cesari, Aglioti, & Urgesi, 2012).

The neural correlates underpinning some of these abilities have been investigated in studies using transcranial magnetic stimulation (TMS). These studies have shown increased activation in selective areas of the motor cortex in expert participants but no motor cortex modulation in novice participants (Aglioti et al., 2008; Tomeo et al., 2012). As with vision, these types of studies have shown that action recognition through sound alone seems to also be modulated by experience (Chen, Penhune, & Zatorre, 2008a, 2008b; D'Ausilio, Altenmüller, Olivetti Belardinelli, & Lotze, 2006; Lahav, Saltzman, & Schlaug, 2007; Zatorre, Chen, & Penhune, 2007). In particular, fMRI studies have shown that once novice piano players have learned a musical piece, motor areas are activated just by hearing the same piece again, while no activation is found when they hear different musical pieces (Lahav et al., 2007). A TMS experiment has supported the importance of motor experience by showing a higher motor evoked potential for finger muscles in amateur piano players when they listen to a previously rehearsed piano musical piece compared to hearing a non-rehearsed piece played on a flute (D'Ausilio et al., 2006). An fMRI study also showed greater activation in the pre-motor and motor areas of the cortex when expert tennis or basketball players listened to sports sounds from their own sport, compared to sounds from a different sport or non-sporting sounds (Woods, Hernandez, Wagner, & Beilock, 2014). These findings suggest that sound

contains relevant information about an action-related event that not only facilitates the re-enactment of the listened-to action in quite a sophisticated manner (Cesari, Camponogara, Papetti, Rocchesso, & Fontana, 2014; Young, Rodger, & Craig, 2013; Young, Sherve, Quinn, & Craig, 2016) but also allows for the extraction of key dynamic kinematic features. For example, it has been shown that by listening to the sound of footsteps when walking, humans are able to pick up and use the timing and velocity features of the gait pattern along with the force exerted on the ground to produce strides of different lengths (Turchet, Camponogara, & Cesari, 2015; Turchet, Serafin, & Cesari, 2013; Young et al., 2013; Young et al., 2016). These examples highlight the importance of not only assessing what auditory information is picked up and used by the perceiver, but also how the sound is ‘brought into use’ to regulate action (Steenon & Rodger, 2015; Rosenblum et al., 2016). In other words these studies highlight the importance of sensory information in the guidance of action (Lee, 1998).

The question of how action-sounds may be perceived in relation to their potential use raises another theoretical issue with regards to the action capabilities of the perceiver. Following on from Gibson’s concept of ‘affordances’ (Gibson, 1979), structures or events in the environment, which support or invite different behaviours, do so in relation to the capacity of the perceiver to act successfully upon them. For example, the physical geometry of a stair supports climbing for an adult, but not for a toddler whose own physical and coordination capacities are not yet sufficiently developed (Cesari, Formenti, & Olivato, 2003). Action-capabilities may be species-specific, developmental, or may be determined by the relevant skill level of the perceiver-actor. For example, expert soccer goal-keepers were found to be better than novices at detecting and acting upon the spin that influence the ball flight path in curved free kicks in soccer (Dessing & Craig, 2010). Interestingly, this expertise-dependent advantage was not found in a similar ball-curve perception only task in which participants simply had to judge, ahead of time, whether a free-kick would result in a goal or not (Craig et al., 2009). This suggests that the effects of skill-based action-capabilities on perception may be more strongly manifested when perception is coupled to action

and the task requires participants to act on the perceptual information in a manner appropriate to their domain of expertise (Brault et al., 2012; Correia et al., 2012; Dessing & Craig, 2010; Watson et al., 2011). This question was explored here by having novice and expert basketball player perform a more ecologically-valid action-response task (virtual full-body blocking of a perceived attacking player – expertise specific), in addition to a generic perception-action task (moving a slider in the perceived direction of the attacking player – non-expertise specific). Whilst evidence has shown that motor resonance through vision allows elite athletes to infer the consequences of a motor act (Aglioti et al., 2008), our aim here is to see whether athletes are able to use the information embedded in the sound of an action to infer intention and if action-relevant experience enhances this ability. With this in mind we compared basketball and non-basketball players' ability to use auditory information to anticipate whether an attacking player was performing deceptive or non-deceptive basketball movements in two different experiments. The first study, called the Slider Task, required a simple action response where the participant had to slide his/her finger laterally along a rail in the direction he/she thought the player was going to pass (i.e. to the left or to the right). This experiment did not require the participant to have basketball specific motor abilities but was more concerned with the ability to detect the auditory information that would specify final running direction. The second experiment, called the Full-body Task, required the participant to move his/her whole body in the direction (left or right) in which he/she thought the player was going to pass. This second experiment was designed to be more life-like and to re-create an expertise context similar to the one that players would normally experience when playing basketball. This design allows us to test for expertise effects where the energetic demands (i.e. incorporating full body movement) are increased and the specific motor skills developed through years of training are required to successfully perform the task. We hypothesize that humans are able to anticipate another person's action intention from only the sound of that action, and the perceptual information specifying action intention, along with the resonant action system, allows the participants to prospectively guide their movements. We also hypothesize that this ability will

be enhanced in people with action-relevant training and experience, namely experienced basketball players who will participate in this study.

## Method

### Participants

Experiment 1 (Slider Task): The basketball group consisted of 9 participants (7 male, 3 left handed, mean age =  $22.2 \pm 3.08$  years) with basketball playing experience. The non-basketball group consisted of 14 participants who had no experience playing basketball (6 male, 2 left handed, mean age =  $27 \pm 9.20$  years). None of the participants reported any kind of hearing impairment.

Experiment 2 (Full body Task): The same group of 9 basketball players who took part in experiment 1 also took part in experiment 2. Ten out of the 14 non-basketball players who took part in the first experiment (6 male, 2 left handed, age  $25.8 \pm 8.65$  years) also took part in experiment 2. Basketball players were recruited from the University basketball team. They trained, on average, 6 hours per week and had been playing basketball for 10.2 years ( $sd=4.49$ ). The two experiments were carried out 48 hours apart. The School of Psychology ethics committee at Queen's University Belfast granted ethical approval for the study.

### Materials and Procedure

#### Action sound stimuli

Two binaural microphones (Roland CS 10 EM) were inserted into the acoustic meatus of a dummy head. These microphones were used to record the sounds of a basketball player's movements including the bouncing of the ball. The dummy head was positioned on the floor to represent the position of a defender. A professional basketball player (32 years of age and 23 years of basketball playing experience) (from now on called 'the attacker') performed different runs while bouncing a basketball as he moved towards the dummy head (Fig. 1). The main idea was to record sounds that



were as naturalistic as possible and that represented the perspective of a defending player. The sounds for both deceptive and non-deceptive runs were recorded. A deceptive movement was classed as a movement to the right or left followed by a sudden switch in the opposite direction to pass the defender (making the action more difficult to predict) while a non-deceptive movement involved a simple change in direction to pass the defender on the left or right. The attacker started 15 meters from the dummy head and ran, while bouncing the ball, towards a pre-defined point located 1.6 meters from the dummy head (defined by expert basketball players as the optimal distance for an attacker to change running direction) (see Fig. 1). The attacker was asked to execute four different types of action that would result in four different sound stimuli (right and left are considered with respect to the defender):

- 1- Non-deceptive R – running straight then moving to pass the defender on his/her right
- 2- Non-deceptive L – running straight then moving to pass the defender on his/her left
- 3- Deceptive L – running straight moving to the right then abruptly switching to pass the defender on his/her left
- 4- Deceptive R - running straight moving to the left then abruptly switching to pass the defender on his/her right

\*\*\* Insert Figure 1 here\*\*\*

### **Capturing the attacker's movement kinematics**

A total of 41 passive markers were attached to the body of the attacker at key anatomical landmarks to capture his movements at 100 Hz using 8 Vicon infrared motion capture cameras. The cameras were positioned around the basketball court so that they would capture a rectangular area of 6x4 meters. The Plug-In gait model was used to analyze the movements of the participant. The Center Of Mass (COM) displacement was calculated using the Vicon Nexus software, which allowed us to define an effective versus an ineffective deceptive movement by applying a method similar to that

used by Brault et al, 2010 (Brault, Bideau, Craig, & Kulpa, 2010). The software also allowed us to time-align the recorded sound with the attacker's movements.

Based on Brault et al's (2010) classification we categorized the recorded movements and their associated sounds into 3 different levels of deceptive movement: i) high, ii) medium and iii) low. In order to decrease any participant expectancy that a deceptive movement was always going to occur, sounds relating to 3 non-deceptive movements were also selected to counterbalance the deceptive movement trials. Since the attacker performed the ball bouncing with his dominant hand (right), the sounds recorded were 3 Non-Deceptive on the Left and 3 Deceptive on the Right with respect to the dummy head. To create an equal number of left and right trials, that were identical but varied only in direction, the selected sounds from deceptive and non-deceptive movements were inverted between the left and right channels. In this way sounds were equal in spectrum and intensity for the left and right directions and were not affected by the handedness of the attacker. Sounds were reversed using Matlab (Matlab R\_2012a) and created with the function "wavwrite". A total of 60 trials were presented [(3 deceptive and 3 non-deceptive) X 2 directions (left and right) X 5 repetitions].

### **Analysis of the sounds**

Given that the theoretical basis of this work is around information movement guidance (Lee, 1998), it is important to understand what kind of information participants could pick up and use to inform their decisions about when and how to act (Craig, 2013). To do this the auditory information in the soundtracks corresponding to the actions performed by the attacker's dominant hand (right) were analyzed using deep sound analysis. For each soundtrack we analyzed the sound of each bounce by considering a time window that started at the peak intensity of one bounce to 10 samples before the subsequent one and from which we extracted the Interaural Time Difference (ITD) and the Interaural Intensity Difference (ILD), which are recognized as the main cues that specify a sound's position in space (Blauert, 1997). The ITD for each bounce was defined by means of a cross

correlation analysis between the two stereo channels, while the ILD was defined by a short time average energy analysis, using a time window of 50 frames that corresponded to 113  $\mu$ s. The difference between the Left and Right channels was then computed and the ILD value extracted. According to previous research (Schnupp, Nelken, & King, 2011) the minimum ITD and ILD for perceiving a sound as lateralized are 10-15  $\mu$ s and 0.5-0.8 dB respectively, depending on the sound frequency; the maximum ITD available from the dummy head, based on the head size, was 663  $\mu$ s. Since the soundtracks included the sounds of footsteps, we extracted the footstep ITDs and ILDs by removing the bounce sound for each time window. In order to define whether ITD changed with respect to the ILD, we correlated those two variables together. Since ITD and ILD are the most important cues to use for sound localization, a high coefficient of correlation between them will indicate that the sound can be more easily localized spatially. The analysis of both the bounces and footsteps revealed that the ITD for Deceptive movement remained stable (Fig. 2), but changed for the Non Deceptive one. On the other hand the analysis revealed that Deceptive movement had a clear intensity change (ILD) when the attacker moved to the opposite side when performing the deceptive action (Fig. 3).

\*\*\*\*Insert Figures 2 and 3 here \*\*\*\*

Correlation results showed a high correlation coefficient between ITD and ILD for Non-Deceptive sound number 1 ( $r=0.51$ ,  $p = 0.05$ ) and 2 ( $r=0.95$ ,  $p < 0.001$ ), while no significant correlations were found for the Deceptive movements. According to the definition of “Deception”, the attacker’s intentions have to be disguised by means of a movement that will cause the defender to perceive the incorrect passing direction. This strategy can be appreciated through the sound analysis, where the lack of correlation between ITD and ILD in deceptive movements creates a situation where the movement intention cannot be well defined. For instance, the analysis of soundtrack number 1, showed that both the bounce sound and the footstep sound of this clip contain acoustic information

that could lead a listener to perceive the attacker as moving in a direction opposite to the final passing direction – that is, a deceptive movement. By taking into account the analysis of the sounds produced by the actions together with the kinematics of the attacker's actions we deduced that the most obvious deceptive movement was soundtrack number 1 and the clearest non-deceptive movement was soundtrack number 2.

### **Apparatus and set-up**

In experiment one, the Slider Task, participants had to anticipate the final passing direction from the sound of the attacker's actions by moving their finger to the left or right along a 2-dimensional slide rail. In experiment two, the Full Body task, participants had to still anticipate the final passing direction from the sound of the attacker's action but this time they had to move their whole body to the left or right to block him. The participants' movements in both experiments were recorded using the Qualisys motion capture system. The pre-recorded sound of the attacker was delivered to the participants through an AKG Studio K240 neutral headset. In order to analyze how the sound of action influenced the participants' movement decisions, sound delivery was synchronized with the motion capture system (Qualisys Oqus3 Motion Capture cameras) by means of an Arduino board and the Matlab Psychtoolbox (Matlab R\_2012a). The sound Pressure level was equalized using Audacity software with all sounds being delivered with an intensity peak of 65 dB in order to avoid a startle reflex (Carlsen, Maslovat, Lam, Chua, & Franks, 2011). In the Slider Task, a Qualisys motion capture system with 4 infrared cameras recorded the movement of the tip of the participant's index finger at 200 Hz. A 40 cm rail was fixed near the side of a table, with a ring on a slide positioned inside the rail. In the Full-body Task the same motion capture system was used (11 Qualisys Oqus3 Motion Capture cameras) with 39 reflective markers (Plug-in gait model) being placed on key anatomical landmarks of the participant's body to capture full body movement at a frequency of 200 Hz.

## **Procedure**

In the Slider Task, the participants sat on a chair in front of a table with the index finger of the dominant hand inside the ring mounted on the rail (Fig. 4A). For each participant the chair was adjusted so that the participant sat at a comfortable distance from the table, with their index finger aligned with the center of their torso and the rail placed in front of them. In each trial, the participant was asked to listen to the audio recordings of the attacker and then move his/her finger in the direction where he/she perceived the attacker was going to pass. Participants were encouraged to be as accurate as possible and could change their mind. That is to say, they could initially move right and then switch to move left. The finger movement was recorded for the duration of the sound trial. The trial ended when the sound passed by the side of the participant. In the Full-body Task, participants were asked to stand in the center of the calibrated area in a typical basketball defensive position (this was demonstrated by the experimenter), and listen to the sound of the attacker moving towards them (Fig. 4B). This time the participant was asked to move his/her whole body in the direction where he/she perceived the attacker would pass. This task was more akin to a real basketball scenario where the participant was moving his/her body to block the attacking player. As in experiment 1, the participant could change his/her mind and the whole body movement was recorded for the duration of the sound trial. For both experiments, movements from a total of 60 trials were collected for the 12 different action sounds [(3 deceptive and 3 non-deceptive) X 2 directions (left and right) X 5 repetitions].

\*\*\*Insert Figure 4 here\*\*\*

## **Results**

### **Kinematic data analysis**

In light of the previous analysis, data collected for trials using deceptive sound number 1 and non-deceptive sound number 2 were subsequently analyzed. For the Slider Task, the kinematic signals

of each participant's movements were filtered using a second order Butterworth filter set at 20 Hz. The lateral-lateral direction was extracted and the following measures were calculated: i) percentage of errors (i.e. participants' initially moved in the wrong direction), ii) the difference in time between movement initiation and the time when the attacker reached the central point (see Figure 1), iii) movement duration and iv) peak velocity. We expected basketball players to be more accurate in defining the attacker's final running direction. We also predicted that basketball players would move earlier when hearing non-deceptive movements but wait longer when hearing deceptive movements (to pick up more information to inform the correct action choice – see Dessing & Craig, 2010; Brault et al, 2012). An in-depth analysis of each variable allowed us to draw a clear picture of the anticipatory abilities of both basketball and non-basketball players. To clarify, *Percentage of errors* was determined as the number of times that a participant was fooled (i.e. moved initially in the wrong direction). This was calculated by means of a Matlab algorithm that defined whether the medio-lateral displacement of the participant was initially in the opposite direction with respect to the final running direction of the attacker. For each soundtrack, the percentage of times that the participant was fooled was then calculated. *Movement initiation time* was taken relative to the time when the attacker reached the central point ( $t=0$ ) and was defined as the instant after the start of the sound clip when the derivative of the displacement reached 5% of its peak value (Bertuccio and Cesari, 2010). This could result in positive or negative values. Negative values indicated that the participant moved *before* the attacker's foot reached the central point and positive values indicated that the participant moved after this point in time. *Movement duration* was calculated as the time from movement initiation to the time when the participant reached the final position with final position being defined as the point when the decrease in movement velocity reached 5% of its peak value.

For the Full-body Task, an analysis of the kinematic data was performed using Matlab R\_2012a software. All the signals were digitally low-pass filtered at 7 Hz, using a second order Butterworth filter (O'Connor, Thorpe, O'Malley, & Vaughan, 2007). The Center of Mass displacement in three

directions (X, Y and Z) was calculated using the Zatsiorsky formula (Zatsiorsky, Seluyanov, & Chugunova, 1990), where the Center of Mass (COM) was derived from 12 defined segments and its total displacement computed. The COM signal in the lateral-lateral direction was then considered.

The same variables identified in the Slider Task were also calculated in the full-body task:

movement initiation, movement duration, peak velocity, total displacement and percentage of errors.

### **Statistical analysis**

All the variables (movement initiation, movement duration, peak velocity, total displacement and percentage of errors) were entered separately into 2 X 2 X 2 mixed ANOVAs, with Group the between-subjects factor, and both Movement (deceptive/non-deceptive) and Direction (left/right) as within-subjects factors. Post hoc analyses were performed using the Bonferroni correction. When Bonferroni corrections were applied, the significance levels of p values were considered accordingly.

### ***Slider Task***

*For clarity it is important to emphasise that movement direction is with respect to the participant (i.e. left is to the participant's left and right is to the participant's right).*

*Percentage of errors.* The ANOVA revealed no significant main effects or interactions in the percentage of errors. During the deceptive movements expert basketball players performed an average of 44.44% (sd = 9.89%) movements in the wrong initial direction, while Non-Basketball players performed 55.33% (sd = 7.66%). This difference between basketball and non-basketball players was not found to be significant ( $p = 0.26$ ). During the Non Deceptive movements Basketball players performed on average 1.11% (sd = 2.88%) of movements in the wrong direction while Non-Basketball players performed 4.00% (sd = 2.23%); again this difference was not found to be significant ( $p = 0.67$ ).

*Movement Initiation.* An Analysis of Variance for Movement Initiation showed a significant main effect for Group ( $F(1,19) = 40.43$ ,  $p < 0.0001$ ,  $\eta^2 = 0.68$ ) and type of Movement ( $F(1,19) = 10.73$ ,  $p = 0.004$ ,  $\eta^2 = 0.15$ ). No other main effects or interactions were found to be significant. Post hoc tests revealed a significant earlier movement initiation time for the Basketball player group (-0.22s (sd=0.09)) compared to the Non-Basketball player group (0.56s (sd=0.07)) ( $p < 0.0001$ ), and for Non-Deceptive (0.07s (sd=0.05)) compared to Deceptive (0.27s (sd=0.08)) movements ( $p = 0.004$ ).

*Movement Duration.* The analysis of variance of Movement Duration showed no significant main effect for Group ( $p > 0.05$ ), but did for type of Movement ( $F(1,19) = 17.66$ ,  $p < 0.0001$ ,  $\eta^2 = 0.21$ ) with a significant Movement X Direction ( $F(1,19) = 4.62$ ,  $p = 0.04$ ,  $\eta^2 = 0.04$ ) interaction. The post hoc analysis for type of Movement showed a longer movement duration for the Deceptive (0.90s, sd = 0.08s) compared to Non Deceptive movements (0.62s, sd = 0.05s) ( $p < 0.0001$ ), while the interaction showed an asymmetry between left and right Non-Deceptive movements, with longer movement durations to the right (0.73s, sd = 0.08s) compared to the left (0.51s, sd = 0.03s) ( $p = 0.009$ ). Longer movement durations for Deceptive (0.85s, sd = 0.08s) compared to Non Deceptive (0.51s, sd = 0.03s) movements were only found for the Left ( $p < 0.0001$ ) (Fig. 5).

\*\*\*Insert Figure 5 here\*\*\*

*Peak velocity.* The ANOVA for Velocity showed a significant main effect for Group ( $F(1,19) = 4.37$ ,  $p = 0.05$ ,  $\eta^2 = 0.01$ ) and also for Movement ( $F(1,19) = 14.88$ ,  $p = 0.001$ ,  $\eta^2 = 0.22$ ). No other main effects or interactions were found. For Group, basketball players moved significantly faster (934.34 mm/s, sd = 59.11 mm/s) than non-basketball players (777.01 mm/s, sd = 46.44 mm/s) ( $p = 0.05$ ), while Deceptive movements resulted in faster movements (955.03 mm/s, sd = 47.24 mm/s) compared to the Non-Deceptive movements (756.36 mm/s, sd = 44.91 mm/s) ( $p = .0.001$ ).

### ***Full-body Task***



*Percentage of errors.* The ANOVA for the percentage of errors showed a significant main effect for Group ( $F(1,15) = 5.80, p = 0.02, \eta^2 = 0.26$ ), Movement ( $F(1,15) = 62.16, p < 0.0001, \eta^2 = 0.66$ ) and a significant interaction for Group X Movement ( $F(1,15) = 6.44, p = 0.02, \eta^2 = 0.06$ ). For Group a significantly higher percentage of errors were found for the Non-Basketball player group (36.91%,  $sd = 4.64\%$ ) compared to the Basketball group (21.35%,  $sd = 4.68\%$ ) ( $p = 0.02$ ), with a significantly higher percentage of errors being found for the Deceptive (53.41%,  $sd = 5.76\%$ ) compared to Non-Deceptive movements (4.00%,  $sd = 2.79\%$ ) ( $p < 0.0001$ ). The interaction Movement X Group showed that the Basketball players had a lower percentage of errors (37.64%,  $sd = 8.15\%$ ) compared to the Non-Basketball player group (67.71%,  $sd = 8.15\%$ ) for the deceptive movements only ( $p = 0.01$ ), no differences for the non-deceptive movements were found ( $p = 0.999$ ) (Fig. 6).

\*\*\* Insert Figure 6 here\*\*\*

*Movement Initiation.* The ANOVA for Movement Initiation showed no significant main effect for Group, but did for Movement ( $F(1,15) = 24.08, p < 0.0001, \eta^2 = 0.11$ ) and Direction ( $F(1,15) = 5.32, p = 0.03, \eta^2 = 0.02$ ). We found a significant interaction for Movement X Group ( $F(1,15) = 24.08, p < 0.0001, \eta^2 = 0.18$ ), Direction X group ( $F(1,15) = 30.02, p < 0.0001, \eta^2 = 0.16$ ) and Movement X Direction X Group ( $F(1,15) = 27.16, p < 0.0001, \eta^2 = 0.21$ ). No other main effects or interactions were found. Post hoc tests for Movement showed an earlier movement initiation time for Non-Deceptive (0.43s,  $sd = 0.06s$ ) compared to Deceptive movements (0.64 s,  $sd = 0.07s$ ), ( $p < 0.0001$ ) while tests for Direction revealed an earlier initiation for movements to the left (0.48 s,  $sd = 0.06s$ ) compared to movements to the right (0.59 s,  $sd = 0.07s$ ) ( $p < 0.0001$ ). The significant interaction found for Movement X Group showed different movement initiation times for Deceptive compared to Non-Deceptive movements in basketball players only, with the earliest movement initiation being found for Non-Deceptive ones (Non Deceptive 0.22s,  $sd = 0.09s$ , Deceptive 0.70s,

sd = 0.10s;  $p < 0.0001$ ). The difference between the two groups emerged only in Non-Deceptive movements, where there was an earlier movement initiation time for Basketball players (0.22s, sd = 0.09s) compared to Non-Basketball players (0.63s, sd = 0.08s) ( $p = 0.004$ ) (Fig. 7). The interaction Direction X Group showed a significant difference between the Left and Right sides for both groups, with an earlier initiation time for the Right (0.53s, sd = 0.09s) compared to the Left (0.68s, sd = 0.08s) ( $p = 0.035$ ) in Non-Basketball players, with the opposite being observed for the basketball players (Left 0.284s, sd=0.09s; Right 0.64s, sd = 0.10s;  $p < 0.0001$ ). The difference between groups was only found for the Left side, with an earlier movement initiation time being displayed by the Basketball player group ( $p < 0.0001$ ).

\*\*\*Insert Figure 7 here\*\*\*

The interaction Movement X Direction X Group showed that a different performance strategy was adopted by Basketball players for both the left and right directions, where they moved earlier for Non-Deceptive (Left -0.06s, sd = 0.10s; Right 0.51s, sd = 0.10s ;  $p < 0.0001$ ) and later for Deceptive movements (Left 0.63s, sd = 0.10s; Right 0.77s, sd = 0.13s;  $p = 0.02$ ) (Fig. 8A). In contrast, the Non-Basketball players behaved differently according to passing direction. They were found to start to move earlier when the movement was deceptive (0.47s, sd = 0.10s) compared to when the movement was non-deceptive movements (0.88s, sd = 0.09s) when the attacker passed on the left hand side ( $p = 0.001$ ), while the opposite was found for cases when he passed on the right-hand side (Deceptive, 0.69s, sd = 0.12s; Non-deceptive, 0.38s, sd = 0.09s,  $p = 0.006$ ) (Fig. 8B). When considering the performance for each Direction and Movement, Basketball players were found to move earlier than Non Basketball players for Non-deceptive movements on the left only ( $p < 0.0001$ ).

\*\*\*Inert Figure 8 here\*\*\*

*Movement Duration.* The ANOVA for Movement Duration showed a significant main effect for Group ( $F(1,15) = 24.08, p < 0.0001, \eta^2 = 0.46$ ) and Direction ( $F(1,15) = 64.50, p < 0.0001, \eta^2 = 0.45$ ). We also found a significant interaction for Movement X Group ( $F(1,15) = 21.05, p < 0.0001, \eta^2 = 0.05$ ) and Direction X Group ( $F(1,15) = 8.08, p = 0.01, \eta^2 = 0.14$ ). No other main effects or interactions were found. Post hoc tests for Group and Direction showed longer movement durations for Non-Basketball players (1.62s, (sd = 0.09)) and movements to the Left (1.63s, sd = 0.09s) compared to Basketball players (1.13s, (sd = 0.09)) ( $p < 0.0001$ ) and movements to the Right (1.12s, (sd = 0.04)) ( $p < 0.0001$ ). The interaction Movement X Group showed longer movement durations for Deceptive (1.24s, (sd = 0.11)) compared to Non-Deceptive movements (1.02s, sd = 0.10s) in Basketball players ( $p = 0.02$ ), while no differences were found for Non-Basketball players ( $p = 0.17$ ) (Fig. 9A). When comparing the two groups, Basketball players (1.02s, (sd = 0.10)) had shorter movement times than Non-Basketball participants (1.68s, sd = 0.09s) for the Non-Deceptive movements ( $p < 0.0001$ ), with both groups moving for the same amount of time for the deceptive movement sounds ( $p = 0.06$ ). The interaction Direction X Group showed that both groups had a longer movement duration for the Left compared to the Right-hand side (Basketball Player Left 1.22s, (sd = 0.13)); Basketball Player Right 1.02s, (sd = 0.06));  $p < 0.0001$ ), (Non-Basketball Player Left 2.02s, (sd = 0.13); Non-Basketball Player Right 1.22s, (sd = 0.06);  $p = 0.032$ ), with Basketball players having a shorter movement duration compared to Non-Basketball participants for both directions (left  $p = 0.001$ , right  $p = 0.05$ ) (Fig. 9B).

\*\*\*Insert Figure 9 here \*\*\*\*\*

*Peak Velocity.* The ANOVA for peak velocity showed a significant main effect for Group ( $F(1,19) = 7.44, p = 0.01, \eta^2 = 0.33$ ) and Direction ( $F(1,15) = 7.32, p = 0.01, \eta^2 = 0.15$ ). No other main effects or interactions were found. The factor Group showed a higher velocity for the Basketball

players (1408.63 mm/s,  $sd = 59.94$  mm/s)) compared to the Non-Basketball players (1183.71 mm/s,  $sd = 56.52$  mm/s) ( $p = 0.01$ ), while Direction produced a higher peak velocity for the Right (1242.64 mm/s,  $sd = 43.78$  mm/s) compared to the Left (1349.19 mm/s,  $sd = 47.50$  mm/s) ( $p = 0.01$ ).

Due to the gender imbalance between groups we ran a further analysis without considering the female sample. Results were, in general, the same as those previously found for all participants except for the Slider task where there was no significant Movement X Direction interaction for “Movement Duration “ and no Group difference for “Velocity”.

### Discussion

In this study we have shown that it is possible to understand and infer another person’s action intention from the information embedded in the sound their actions produce. By listening to the sound of the actions of a professional basketball player, defined as “the attacker”, who performed deceptive and non-deceptive movements, we were able to assess whether humans can infer action intention when only having access to the sound an attacker’s movements made. Secondly, we wanted to see if experience of the action context plays a key role in trying to predict action intentions of others using sound. To do this we used two perception-action experiments, one requiring small, relatively easy lateral movement responses (non-expertise specific) and the other requiring full-body responses like those required in a real basketball game (expertise specific). In both experiments, we showed that the information embedded in the sound of an action was sufficient to accurately inform participants’ movement responses. This supports the ‘supramodal brain’ theory (Rosenblum et al., 2016), which states that if information specifying an event is available through different sensory channels, then the brain will make use of that information to support performance of the current task, regardless of which channel it is detected through. In this case, information for the player’s movement direction, which would otherwise be picked up through vision, was accurately detected through sound. However, for basketball players we found an earlier

movement initiation time, a lower displacement velocity, and a shorter overall movement time in non-deceptive compared to deceptive movements which allows us to conclude that experts are better able to pick up the auditory information that specifies deception in movement (see analysis of sound in the methods section) and use this information to anticipate an attacker's action intentions. Indeed, the sound analysis showed that the ILD and the ITD were differentially correlated and distributed for deceptive and non-deceptive movements. The sound of deception was characterized by a constant ITD and a change of the ILD only immediately after the sound reached the central point. Moreover, for deceptive sounds there was a lack of correlation between the ITD and ILD variables. In contrast, for non-deceptive movements there was always a defined ITD and ILD predominance on one side (see section 2.4, figures 2 and 3) along with a strong correlation between the two. Our results show that basketball players were better at picking up this action specific information and using it to anticipate the attacker's future position more quickly and accurately than non-basketball players.

When considering the Slider task, we found no differences between the two groups for all the variables apart from movement initiation and movement velocity. Here we found that the basketball players moved earlier and faster than non-basketball players, indicating that our basketball players were quicker at picking up relevant sound-based information, allowing them to act in a more confident way compared to the non basketball players. It would appear that when the attacker was moving in a specific direction, both the sound of the angular trajectory of the ball and his footsteps produced a specific sound intensity profile, with associated timing cues, that directly mapped onto the kinematic movement features of the action being performed. It is this *action specific sound information* that is then picked up and used by the participant to *anticipate* the attacker's final running direction. This sound information has to be prospective in nature so the participant can use it to act ahead of time to get to the right place at the right time to 'intercept' the passing attacker (Brault et al., 2012; Lee, 1998).

As highlighted in previous studies, it is through the structural and transformational invariants present in the sound (Thoret, Aramaki, Kronland-Martinet, Velay, & Ystad, 2014), that participants can anticipate the attacker's movement kinematics (e.g. velocity, trajectory, position). In other words, changes in the sound envelope directly map onto the attacker's action intentions, coupling the information to the movement produced. As a result, a participant can use this information to guide their movements accordingly. Interestingly, basketball players were able to accurately anticipate the attacker's future running direction after 200 ms when it was non-deceptive. This anticipatory skill in basketball players is in line with a basketball study which showed that when vision was temporarily occluded basketball players were able to more accurately predict the outcome of a basketball shot above chance level, about 213 ms *before* the ball left the player's hand, compared to novices who could not predict until 71 frames *after* the ball left the player's hand (Aglioti et al., 2008).

In this study, we found that the role of expertise in the perception of action through sound became more pronounced when participants had to engage in a basketball specific action and coordinate the movement of their whole body to intercept the attacker. In this situation, expert basketball players were able to more accurately recognize deceptive movements compared to their non-basketball counterparts (Fig. 3). Our results showed that basketball participants made movements in the wrong direction only 37% of the time in the Full Body Task, compared with 44% when performing the Slider task. Our non-basketball participants, on the other hand, performed more movements in the wrong direction when doing the Full-body task than when doing the Slider task (67% and 55%, respectively). These results, collectively, support the notion that action-capability effects on perception are more pronounced when perception and action are coupled and the perceiver can use the information to prospectively control action in a manner appropriate to their domain of skill (Craig & Watson, 2011; Van der Kamp & Renshaw, 2015). These findings further reinforce the need to carefully consider the design of perception based experiments to ensure that the task is

ecologically valid and is representative of how perception is used to inform decisions about action in everyday life (Brunswik, 2003).

Being able to accurately pick up an attacker's action intentions from the sensory information available and anticipate final running direction, is a skill that is acquired through a combination of visual (Aglioti et al., 2008; Tomeo et al., 2012) and auditory information that is generated whilst interacting in a task-specific context (Camponogara, Komeilipoor, & Cesari, 2015). In addition, we found that only the basketball players adopted two separate strategies for deceptive and non-deceptive movements. When confronted with a deceptive movement, basketball players waited longer, to pick up more auditory information to be more fully informed of the attacker's final running direction whilst in the non-deceptive movements, they moved as soon as they heard and understood the attacker's intention. As has also been shown in visual studies (Dessing and Craig, 2010; Brault et al., 2012), experts can read action intention by tuning into information that specifies true running direction, namely the displacement of the COM of the attacker. By disentangling the honest from the deceptive signals, experts wait that bit longer before they move (Brault et al., 2012). Interestingly, this time corresponds to 200 ms after the attacker reaches the centre point, which underlines the anticipatory nature of the information being used in action guidance. This suggests that participants in this experiment had picked up information that specified the attacker's action intentions early on in the event, which facilitated the coordination of their whole body to start to move at the right time to successfully intercept the attacking player. This strategy was consistent for both directions (left, right) in basketball players (Fig. 8A), whilst not in non-basketball players (Fig. 8B) and further confirms how experts can clearly tune into the relevant sound information that specifies the differences in the kinematics of deceptive and non-deceptive movements. Movement duration results confirmed this approach as being consistent, and showed that only experts adopted two different strategies with respect to the two different types of movement they heard (Fig. 9A). This, along with a high COM Velocity found in the basketball players confirms that the level of sensitivity in action planning is related to the level of experience of the listener (Cesari et al., 2014).

The difference in action anticipation between the slider task and the full body task also showed that the basketball players' superior task-relevant experience helps them extract pertinent action information in the early stages of the movement (Abernethy & Zawi, 2007). This highlights the importance of the unfolding pattern of the attacker's movements in informing and guiding choices about when and how to act in an anticipatory way (Brault et al., 2012).

It is also interesting to note the unexpected effect that the direction of the attacker had on movement initiation times, and in particular in the full-body task that the experts responded faster when the player was going to pass on the left than on the right in the non-deceptive trials, but that the novices showed the opposite effect (Figure 7). This would suggest that there is a lateral asymmetry in the action-capabilities of the participants in this task, and that basketball training and experience may reverse this asymmetry. It is possible that if the majority of basketball players are right-handed, then the distance between the defender and the ball is smaller when an attacking player passes them on the right than when they pass on the left, and so would require less time to initiate movement. It seems that if this is the case, then the expert players respond to the sounds in a way that reflects this inherent lateral asymmetry in action-time cost, whereas novices do not. This is an interesting hypothesis about how skill-based action experience may influence perception-action strategies that should be investigated in future studies.

Although the studies reported here examined behavioral data, we can speculate about the underlying neurophysiological processes, which might be involved in the coupling between perception of kinematic information and action control. Neurophysiological data has shown that neurons in the premotor and parietal cortex are activated during the execution and also the observation of a given action (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Romani, Cesari, Urgesi, Facchini, & Aglioti, 2005). In macaque monkeys, it has been shown that certain neurons are activated by both seeing and/or hearing actions, as well as by performing the same actions (Kohler et al., 2002). Moreover, neural activation caused by performance and perception of



the same action has been found to be greater for familiar compared to unfamiliar actions (Calvo-Merino et al., 2005). It could be supposed that what was observed in the present studies is analogous to the one described in visual studies, that is when people heard the sound of the action, cortical areas that would be involved in the execution of the same movement kinematics may be activated (Aglioti & Pazzaglia, 2010; Aziz-Zadeh, Iacoboni, Zaidel, Wilson, & Mazziotta, 2004; Bidet-Caulet, Voisin, Bertrand, & Fonlupt, 2005; Kohler et al., 2002; Lahav et al., 2007; Pizzamiglio et al., 2005). This suggests that common populations of neurons can detect the relevant kinematic action based information (Cesari et al., 2014; Thoret et al., 2014; Young et al., 2013), recognize the action (Rizzolatti & Craighero, 2004) and use this information to predict the actor's intentions (Gallese & Goldman, 1998; Iacoboni, 2009; Iacoboni et al., 2005). In this context, motor expertise is crucial for picking up essential movement information (Abernethy & Zawi, 2007) and anticipating the player's action intention (Aglioti et al., 2008; Tomeo et al., 2012). Through practice, it is hypothesised that the processing of task-relevant kinematic patterns (observed, heard, and/or performed) of the action is enriched and consolidated (Gallese, 2000). In keeping with the supramodal brain theory, the kinematic pattern created by the action resonates in the perceiver's own motor system whether the sound is seen or heard (Aglioti & Pazzaglia, 2010, 2011; Cesari et al., 2014; Kohler et al., 2002; Lahav et al., 2007; Pizzamiglio et al., 2005; Rizzolatti & Craighero, 2004). Although this account is consistent with our findings, the actual neural processes supporting pick-up and use of information about another person's action through sound is in need of further investigation.

In conclusion, our study demonstrates that the information in the sound of human action specifies the movement kinematics of that action, which in turn supports the perception of the actor's intentions. Moreover, we show that experience itself shapes and refines this perception, allowing for the extraction and elaboration of relevant movement based information in the early stages of the movement so that the participant can act in an anticipatory way. Experience became more pertinent

when participants had to coordinate whole body movement in order to intercept the virtual attacker; with skilled players showing that they could use auditory information to guide their action in a consistent way. Through these perception/action experiments we have shown that we can infer and respond to an actor's intention by listening to the sound of the action alone. We have shown how information embedded in the sound maps onto aspects of the action, and that information can be picked up and used more accurately by a group of experts to accurately anticipate the future running direction of an attacker.

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**Figure Caption**

Figure 1: A schematic representation of the running direction of the attacking basketball player during the recording of the sound stimuli. The black footprints represent a deceptive movement to the right (initially moving left and then making a sharp change in direction to the right) while the blue footprints represent a non-deceptive movement to the left (running straight then making a simple direction change to the left). Right and left directions are considered with respect to the dummy head for both the sound capture and with respect to the participant in the two experiments.

Figure 2: ITD values for each bounce in each sound from the recordings taken from the attacking basketball player running towards the dummy head. The arrow indicates the bounce at which the attacker turned left or right after previously running in a straight line (Central Point).

Figure 3: ILD values for each bounce in each of the six sound recordings used in the experiment of the attacker running towards the dummy head. The arrow indicates the bounce at which the attacker turned left or right after running in a straight line (Central Point).

Figure 4: Representation of the setup of the Slider task (Finger movement) (A) and the Full body movement task (B).

Figure 5: Slider task: The mean time taken to move the slider to its final position for each Direction (Left/Right) and for each Movement (Deceptive/Non-Deceptive). Error bars represent the standard error. The symbol \* indicates a level of significance at  $p < .05$ , the \*\* indicates a level of significance at  $p < .001$ .

Figure 6: Full-body task: The percentage of errors for Basketball (black columns) and Non Basketball (white columns) players for Deceptive and Non-Deceptive movements. Error bars represent the standard error. The symbol \* indicates a level of significance at  $p < .05$ .

Figure 7: Full-body task, mean time taken to initiate full-body movements for the two groups (Basketball and Non-Basketball) in both Movement conditions (deceptive and non-deceptive). Error bars indicate the standard error. The symbol \* indicates a level of significance at  $p < .05$  the \*\* indicates a level of significance at  $p < .001$ .

Figure 8: Full-body task, mean Movement Initiation Times for the Basketball (A) and Non-Basketball groups (B) during the Deceptive and Non Deceptive movements in both Directions. Error bars indicate the standard error. The symbol \* indicates a level of significance at  $p < .05$ , the \*\* indicates a level of significance at  $p < .001$ .

Figure 9: Full-body task, mean Movement Durations for each Movement (A) and Direction (B) within each group. Error bars indicate the standard error. The symbol \* indicates a level of significance  $p < .05$ , the \*\* indicates a level of significance at  $p < .001$ .